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**EVALUATION OF JSAF EM PROPAGATION PREDICTION METHODS FOR NAVY CONTINUOUS TRAINING ENVIRONMENT / FLEET SYNTHETIC TRAINING,
RESULTS AND RECOMMENDATIONS:
PART II – POTENTIAL IMPROVEMENTS TO PROPAGATION MODELING WITHIN JSAF**

by

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ABSTRACT

Incorporating the Navy's Advanced Propagation Model (APM) into JSAF would greatly improve the EM range prediction accuracy, particularly for situations with strong refractive effects such as commonly occur in the Mideast and other locations. Many, but not all, of the various physical effects on EM transmissions are already included in the APM model and therefore would not require development by NWDC. Because APM is the official OAML EM propagation model for the Navy, there will be continuous improvements and it will not stagnate. Incorporating these improvements into JSAF should be relatively straightforward because most of them will be internal to the program and not require any extra changes to the JSAF "sockets" that allow input and output of data between APM and the rest of JSAF. Including some of the physical effects, besides refraction, would require significant costs to NWDC in terms of programming effort. They would also contribute more complexity to the user interface. A later report will analyze the associated costs and benefits to various modeling improvements and compare these with the cost/benefits of enhancing the environmental inputs. This analysis will serve as an aid to decision makers who will determine which features should be the focus of JSAF developments now and in the future.

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POTENTIAL IMPROVEMENTS TO PROPAGATION MODELING WITHIN JSAF

A. INTRODUCTION

The previous report by the authors, “Part 1 - Evaluation of Current JSAF EM Propagation Modeling”, revealed several weaknesses in the way that JSAF models Electromagnetic (EM) EM propagation. These weaknesses were in regard to how JSAF models atmospheric *refraction*. There are other atmospheric and surface processes and features that also affect EM transmissions that are not included in the current JSAF, but which are available in more sophisticated EM propagation models such as the Advanced Refractive Effects Prediction System (AREPS) and the Advanced Propagation Model (APM) that is at the core of most AREPS predictions. In this report, we discuss various refractive and non-refractive effects, and what would be required to incorporate predictions of these effects on EM propagation into JSAF. The goal is to provide the reader with information on how important these features are so that an informed decision can be made as to whether the cost of implementing these prediction capabilities is worth the expected benefit to JSAF users, i.e. improved prediction capability that would come from including modeling these various factors.

For each of the following potential changes or additions to the JSAF EM propagation prediction system, we attempt to address the following issues: (I) the benefits of implementing the change and (II) the estimated costs associated with making the potential change. At this point, many of costs are estimated in a qualitative sense; quantitative assessments will require more careful study and collaboration with NWDC staff. These costs are addressed: (1) development costs, (2) implementation costs, (3) maintenance costs, (4) execution time, (5) data storage (6) user interface complexity and (7) other costs that may apply. Costs (1)-(3) represent monetary costs to NWDC, due primarily to labor requirements, Costs (4)-(6) represents costs that might affect the JSAF user experience and ability to use the program in an efficient way.

B. MAIN MODEL (REFRACTION)

JSAF uses the FFACTR model from the EREPS tactical decision aide (TDA) for EM propagation. This is a prediction model which has not been updated or used operationally by the Navy for over 20 years. The previous report showed several deficiencies in the model and how replacing this “main” model would result in greatly improved accuracy and realism. The obvious candidate for replacement is the Advanced Propagation Model (APM) which was developed and is maintained by SPAWARS SSC Pacific. APM is the official OAML(Oceanographic and Atmospheric Master Library) approved Navy EM propagation model and it is the core program for many of the predictions performed by the Advanced Refractive Effects Prediction System, which is an OAML TDA that is used operationally in the fleet. AREPS/APM is undergoing continuous improvement; in fact a major modernization effort is being performed this year (2012). Although APM is the core model used in AREPS for most situations and this would be the model incorporated into JSAF initially, there are many other aspects of EM propagation such as target cross sections, receiver and transmitter characteristics and other physical features such as sea state and ionospheric conditions that must be

considered for accurate range predictions. These other aspects are not contained in APM, but are addressed in AREPS.

The APM model is developed and maintained by SPAWARS SSC. The implementation costs for replacing FFACTR with APM should be relatively modest because the same "sockets" currently used by FFACTR for input and output of data should be the same, and therefore swapping the models should not be very difficult. APM is written in FORTRAN and can be compiled for LINUX platforms. However we should note that APM only predicts propagation loss and/or propagation factor and does not provide absolute signal strengths, probabilities of detection or maximum range. These require the use of data sets of target, transmitter and receiver characteristics that are part of AREPS, but not APM. These introduce considerable complexity to the task of providing JSAF users with accurate range predictions. Maintenance costs for NWDC are expected to be light because once implemented, APM should not require tuning or modification by NWDC personnel. New versions of APM will be made available by SPAWARS SSC, but these should not change the way the model is executed or implemented. In most situations, APM runs quite quickly, i.e. less than 1 second for a single specified environment and system parameter scenario for a single transmitter to receiver (or target) path. High elevation (aircraft) and higher frequency radiation can slow down execution time considerably. Also, production of 2D "performance surfaces" could take several minutes execution time because many separate runs must be performed (one for each point in the performance surface.) However, because APM is a hybrid system that uses a parabolic equation solver in combination with other techniques (for higher propagation angles) it runs more efficiently and quicker that many other types of EM propagation models. For most situations, time delays due to APM run time in JSAF should not be noticeable by the users. The data storage requirement for APM input and output for a particular scenario is not large, typically less than 1 Mb. Incorporating APM into JSAF without any other changes could be transparent to the user (except for the range predictions); there should be no need to change the user interface. However, later recommendations will include features that would change the environmental editor, but that is not required for APM to run within JSAF.

C. SURFACE CLUTTER

Radars are affected by reflections from surface features, and over the ocean this includes waves. During higher sea states, when waves are larger and wave faces are steeper, the radar operator will see clutter that makes target detection more difficult and results in shorter detection ranges. The current JSAF does not consider the effects of surface clutter on detection range, while APM does have this prediction capability. Negligible model development would be required to incorporate this feature into JSAF because it is already included in APM. Implementing a surface clutter model would require a moderate effort by NWDC programmers because information on ocean surface waves would need to be inputted into the APM calculations. If direct information on waves is not available, local wind speed could be used as a proxy for wave state. The added maintenance costs for NWDC personnel should be minor because this aspect should not need any special attention once it is implemented and any and all modifications will be performed by SPAWARS SSC. Including surface clutter effects

doubles the execution time of APM because the model needs to run twice, once to determine the radiation impacting the surface and again to model the return reflections. There would be no significant increase in data storage needs. The user interface would probably need to be changed to give the user the option to include this feature and to input wave state if this is not automatic.

D. GASEOUS ABSORPTION

EM radio waves are attenuated by absorption from gas molecules, primarily water vapor. The effect is usually not large, but including it would be expected to make the predictions more accurate by reducing the detection ranges. The calculation requires a specification of the water vapor in the atmosphere. The option to perform gaseous absorption is already included in APM so as with surface clutter, so no extra development effort would be required by NWDC programmers. There would some programming required to allow a user interface or automatic input of the water vapor concentration. The extra computation time for this feature is negligible as are the extra data storage requirements. The user interface would need to be changed to allow specification of water vapor or the choice of whether this calculation should be performed.

E. TROPOSCATTER

Troposcatter is a phenomenon by which turbulent fluctuations in the atmosphere, usually at the tropopause (at the top of the troposphere) scatter radio signals and can allow greatly extended over-the-horizon UHF communication ranges. It requires powerful transmitters and sensitive receivers. It also requires profiles of temperature, humidity, pressure and winds throughout the troposphere. APM currently can perform troposcatter predictions over ocean areas but not land. Including troposcatter for over ocean transmissions would require only minor development effort by NWDC because it is included in APM. Some programming would be required to give the user the option for the JSAF simulations to perform troposcatter predictions. The added computer time for troposcatter is very small. There would be a need for a small amount of extra data storage for the atmospheric profiles required. The environmental data editor in JSAF would have to be modified to include a troposcatter option.

F. PRECIPITATION EFFECTS

Precipitation can have a significant effect on EM radio transmissions, particularly in the microwave and higher frequency region of the EM spectrum. For radar performance, this effect is not as “tricky” as some of the other more subtle effects on detection range, because it is usually obvious to the radar operator when precipitation is affecting performance. Precipitation effects are not currently in either the JSAF or APM models. However there is a development effort at SPAWARS SSC to include this effect and it is estimating it will be included in APM in 12-18 months. The cost of implementing these effects into JSAF would be quite high because there would be need to specify three-dimensional fields of precipitation including phase (water or ice) and concentration. There would also be a moderate data storage cost as these fields would

need to be accessed. The added computational time for including precipitation effects would be relatively small. The JSAF user interface would need to include an option for including a precipitation effect option, or it could be automated.

G. ATMOSPHERIC HORIZONTAL VARIABILITY

In many locations the important factors that control refractivity and some other factors can vary over a transmission path. Atmospheric horizontal variability (heterogeneity) can be especially strong in coastal regions, across atmospheric fronts, over land regions with significant topography and other regions. The current JSAF has no capability for accounting for this; conditions are assumed to be constant (homogeneous) along the transmission path. This is a major capability of APM--it allows inputs for several different refractivity profiles along a transmission path. Incorporating atmospheric horizontal variability would add considerable complexity to JSAF simulation and would require considerable programming cost. However, JSAF does allow horizontal variations in ocean acoustics predictions so some of currently-used assets could perhaps be used for including variations in atmospheric properties. APM execution time is the same for heterogeneous and homogeneous environments. There would be a need for some increased data storage. Considerable changes to the user interface would be required if manual inputs of different conditions in an area are included in JSAF.

H. LAND TERRAIN AND DIFFRACTION

Including terrain (i.e. topography) and the associated diffraction effects are essential for accurate over land EM predictions. JSAF does include topography, but does not have the capability of predicting its effect on EM transmissions, a serious weakness for over land simulations. This is another major capability of APM; it can include terrain effects and the associated blocking and diffraction effects on EM signals. Implementing terrain effects in JSAF would require some extra programming, but because terrain is already included in JSAF this shouldn't be substantial. Including terrain does not add to the APM execution time. The data storage requirements would be significant in situations where high-resolution topographic information is required. The user interface would need similar modifications as those described for including atmospheric horizontal variability.

I. SOIL AND VEGATATION EFFECTS

Soil and vegetation can have strong impacts on near-surface transmissions over land. JSAF currently does not include these effects. AREPS uses soil type information for ground wave propagation but uses a fairly crude data base. No vegetation data is used in the APM/AREPS models. Including soil types in JSAF would require a moderate programming effort and a data base would need to be populated and have the ability to change on a daily basis as moisture conditions change. The increase in APM execution time would be minor. There would need to be storage for a soil data base. The input

interface would need to change to allow user specification of soil types and soil moisture if not automated.

J. HF PROPAGATION

HF or High Frequency communication is still used by the US Navy and other services for long range communications. (Note the term “High Frequency” is somewhat of a misnomer because most communications such as VHF, UHF and microwaves are actually higher frequency that HF.) It is also considered to be a back-up in case satellite communications fail. There are two types of HF propagation: sky waves and surface waves. Sky waves bounce off the ionosphere and can travel large distances, even across oceans and continents. Surface waves use the air-surface interface as a wave guide and can extend well over the horizon, although generally not as far as sky waves. Surface waves are especially effective over ocean areas due to the dielectric properties of sea water. JSAF currently has no HF prediction capability. APM does not include HF but AREPS has a limited HF model and there are plans at SPAWARS SSC to enhance this sub-model in AREPS. Including HF in JSAF would require a substantial programming cost because entirely new models (one for sky waves and one for surface waves) would need to be incorporated. There would be a significant increase in JSAF execution time and there would be increased data storage needs because HF sky waves predictions require ionospheric information that is not currently included in JSAF.

K. CONCLUSIONS ON POTENTIAL IMPROVEMENTS TO THE JSAF EM MODELING CAPABILITY

Incorporating APM into JSAF would greatly improve the EM range prediction accuracy, particularly for situations with strong refractive effects such as commonly occur in the Mideast and other locations. Many, but not all, of the various physical effects on EM transmissions are already included in the APM model and therefore would not require development by NWDC. Because APM is the official OAML EM propagation model for the Navy, there will be continuous improvements and it will not stagnate. Incorporating these improvements into JSAF should be relatively straightforward because most of them will be internal to the program and not require any extra changes to the JSAF “sockets” that allow input and output of data between APM and the rest of JSAF. Including some of the physical effects, besides refraction, would require significant costs to NWDC in terms of programming effort. They would also contribute more complexity to the user interface. A later report will analyze the associated costs and benefits to various modeling improvements and compare these with the cost/benefits of enhancing the environmental inputs. This analysis will serve as an aid to decision makers who will determine which features should be the focus of JSAF developments now and in the future.

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